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Technical Note 1975-30

Winding a Long Coil with a Pre-Programmed Turns Density Variation

M. L. Burrows

S. H. Prince

27 May 1975

Prepared for the Department of the Navy
under Electronic Systems Division Contract F19628-73-C-0002 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS

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A. ORIGINATING AGENCY
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Massachusetts Institute of Technology

B. REPORT TITLE AND/OR NUMBER
Technical Note 1975-30

C. MONITOR REPORT NUMBER
ESD-TR-75-176

D. PREPARED UNDER CONTRACT NUMBER(S)
F19628-73-C-0002

2. DISTRIBUTION STATEMENT

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WINDING A LONG COIL WITH A PRE-PROGRAMMED TURNS DENSITY VARIATION

M. L. BURROWS
Group 61

S. H. PRINCE
Group 76

TECHNICAL NOTE 1975-30

27 MAY 1975

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LEXINGTON MASSACHUSETTS

ABSTRACT

A conventional cable manufacturer's concentric taping machine has been modified to wind a long solenoidal winding with a smooth pre-programmed turns density variation. An interpolating function generator with many adjustable set points is used to define the function of coil length that the turns density is to follow. A machine having this capability is needed to provide a towed ELF loop antenna with the smoothly tapered sensitivity variation it requires to discriminate against vibration noise.

Winding a Long Coil with a Pre-Programmed Turns Density Variation

I. Introduction

A submarine towed ELF loop antenna vibrates longitudinally and transversely during towing. The vibration is driven by the fluctuating surface stresses arising within the turbulent boundary layer surrounding the cable containing the antenna. It has been established theoretically [1-5] and experimentally [6,7] that tapering the sensitivity profile of the antenna reduces these troublesome vibration noises considerably. The tapering involves arranging that the sensitivity of the antenna to an incident signal is maximum in the mid-section of the antenna's total length and goes smoothly from the maximum to zero at each end. It is analogous to tapering the aperture illumination of a more conventional antenna to reduce its sidelobes and thereby also reduce the noise coming from off-axis sources.

The antenna sensitivity as a function of position along the antenna (also known as the sensitivity profile of the antenna) can be tapered by varying the area of the core enclosed by the winding, by varying the permeability of the core, and by varying the turns density of the signal winding (or any combination of these). The first two methods were used in combination in an early design of the antenna [8], but proved difficult to control. The last--turns tapering--was used in the latest and, so far, most successful, design [6,7]. However, the machine used to apply the signal winding, a conventional cable manufacturer's concentric tapering machine, was equipped to wind only a uniform turns density. The tapered turns density was achieved, therefore, by using a stepped approximation to a smoothly sloping turns den-

sity. Unfortunately, the discontinuities in turns density at each step turned out to be the main source of motion-induced noise in the antenna. This could be reduced further by using many more much smaller steps in the approximation. An alternative which is more convenient in the long run is to modify the machine to wind a smoothly-varying turns density, preferably pre-programmed.

The next section describes the modifications made to the machine to give it this capability, and the following one presents the results of a test winding made after the modifications.

It should be noted that another method of tapering the sensitivity profile has been proposed--that of capacitive tapering. A theoretical study [9] concludes that it is a practical method having the advantage over the others that it requires no non-uniform fabrication steps. However, it has yet to be tested experimentally.

II. Machine Modification

An overall view of the taping machine is shown in Fig. 1. The machine's function is to wind a wire or tape onto the core stored on the pay-off reel on the right. The core passes from the pay-off reel, through the axis of the taping head where the winding occurs, under the roller of a footage indicator, over a guide pulley and on to the capstan (the large black wheel at the left end of the machine). The capstan turns at uniform speed pulling the core through the machine. Two more guide pulleys are provided to give enough circumferential contact between the wound core and the capstan. From them, the wound core passes onto the take-up reel at the left. The take-up machine

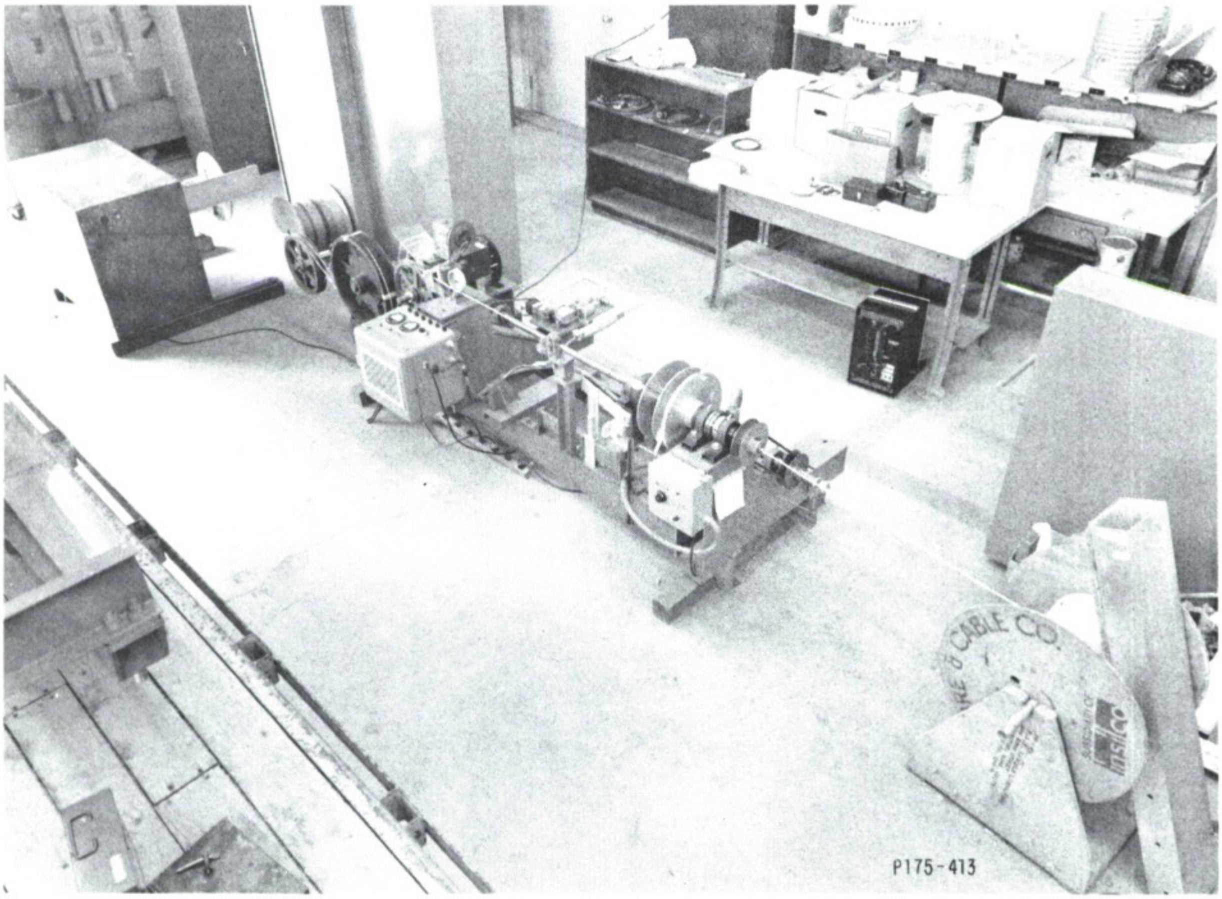

Fig. 1. Overall view of taping machine (center) with pay-off reel (right) and take-up (left). The taping head and capstan are shown at the right and left hand ends of the machine.

maintains tension in the wound core, thereby preventing slippage on the capstan, by being driven with a constant torque.

Before modification, the machine was driven by a single motor which was coupled to the capstan via reduction gearing and to the taping head via an adjustable ratio Reeves drive mechanism. Figure 2 is a sketch of the pre-modification essentials. It was possible to reset the Reeves drive manually while the machine was running, but the range (about 9 to 1) of the Reeves drive was insufficient to encompass the whole range of turns density required for the antenna winding (about 11 to 1). It was necessary, therefore, to stop the machine at some point, change a sprocket in the capstan reduction gear, reset the Reeves drive and then restart the machine again to finish off the whole tapered length at each end of the antenna.

The purpose of the modification, therefore, was to effect a continuous automatic speed ratio variation according to some pre-set program, and to do so over a large enough range that the whole antenna could be completed without stopping the machine.

The sketch of the post-modification essentials given in Fig. 3 shows how it was done. Basically, the capstan and taping head are now driven by separate motors. The capstan motor has a manual speed adjustment which determines the speed at which the core is pulled through the machine. The taping head motor is driven, via an amplifier, by an error voltage proportional to the angular difference in position between one shaft coupled directly to the capstan and another coupled to the taping head. This feedback loop effectively forces the speed of the taping head to be a predetermined multiple of the

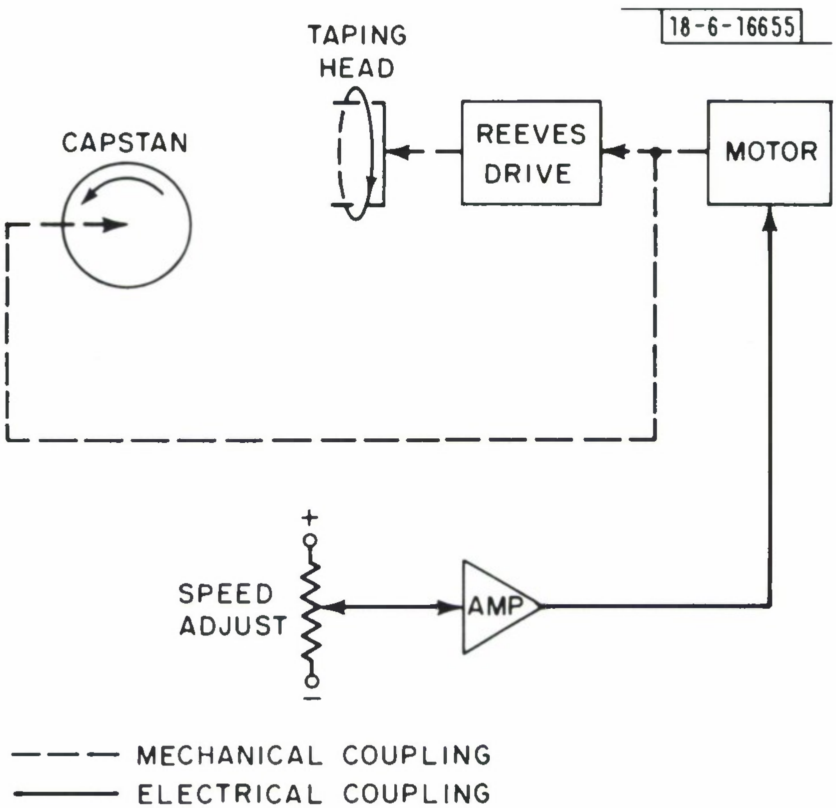

Fig. 2. Taping machine before modification.

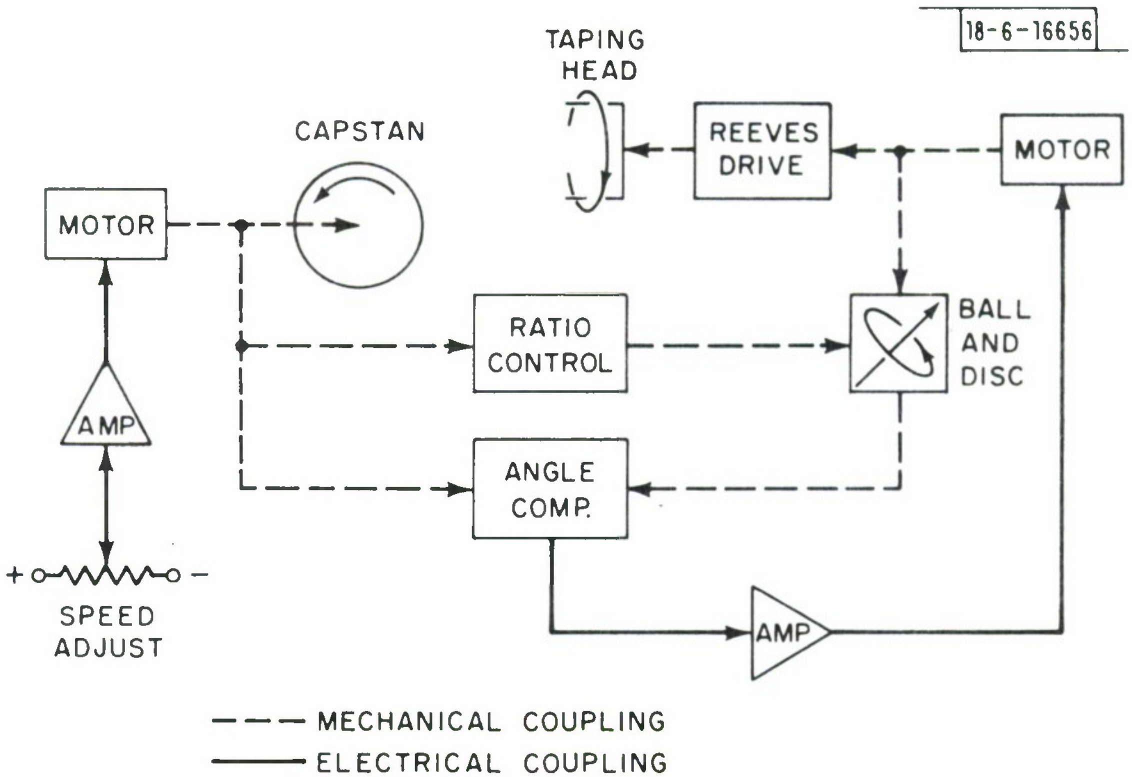

Fig. 3. Taping machine after modification.

speed of the capstan.

However, the shaft driven by the taping head is coupled to it via a variable ratio ball and disc drive whose gear ratio is controlled by a preset ratio controller driven by the capstan. Thus as the capstan turns, pulling the core through the machine, it also drives the ratio controller through its preset program which in turn guides the ball and disc drive through the required gear ratio program. As the gear ratio decreases, the taping head motor must run faster and faster to keep to two input shafts of the angle comparator running at equal speeds. In this way the turns density of the winding at any particular point along the core is pre-determined by the ratio controller.

The Reeves drive is retained in the modified machine, although it is no longer used for varying the turns density during the winding operation. It is normally set at the fixed gear ratio of 1:1, in which case the range of the machine is from 3 turns/inch to 33 turns/inch. By resetting the Reeves drive, however, this 1:33 range can be arranged to start anywhere between about 1 turn/inch and 9 turns/inch.

The ratio controller is an assembly of the four components shown in Fig. 4. The capstan drive is applied to the shaft of a multi-turn potentiometer. There are a total of thirty-four equally spaced connections to the resistance winding of the potentiometer. To each is applied a separate voltage determined by the position of a separate slider control in the 34-slider program table. As the potentiometer slider moves around the potentiometer winding, its output voltage is equal to the voltage applied to a connection, when

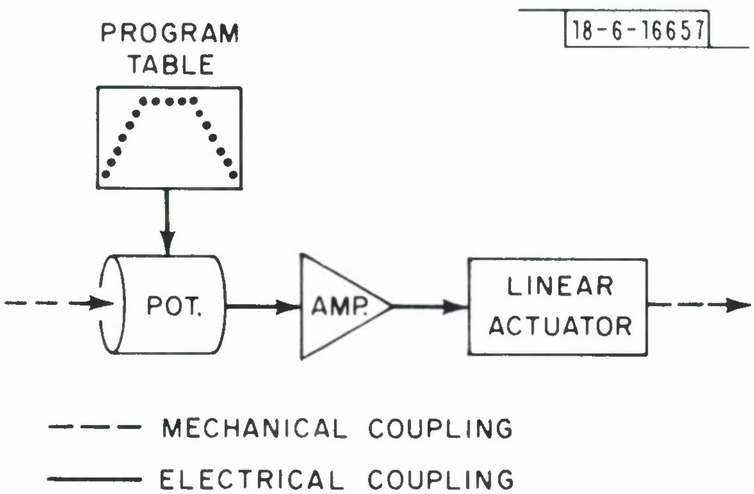

Fig. 4. The four components of the ratio controller.

it rests right on that connection, and is equal to a linear interpolation of the voltage applied to two adjacent connections, when it lies between those two. Thus the output voltage of the potentiometer is a 34-point linearly interpolated approximation of whatever function of core length is desired. This allows the function to be defined in more than satisfactory detail. A photograph of the program table is shown in Fig. 5, where it lies to the left of the main control panel.

A mechanical drive is necessary to control the gear ratio of the ball and disc drive, so the output voltage of the potentiometer is applied, via an amplifier, to a linear actuator which, in turn, drives the ball cage of the ball and disc drive.

A second composite unit shown in Fig. 3 is the box labeled angle comparator. It consists of a synchro transmitter connected to one input shaft, a synchro transformer connected to the other input shaft and a phase sensitive detector at the electrical output of the synchro transformer. The detector output voltage is then proportional to the difference in angular position of the two shafts, provided the angular difference is small compared with a radian.

Figure 6, a rear view of the taping machine, shows, on the rear left, a mounting plate with the ball and disc drive, the taping head synchro and the linear actuator together with its own position servo amplifier. At top right, under the partially lifted protective cover, some of the gearing associated with the capstan synchro and the capstan motor, together with its own tachometer servo speed control, can be seen.

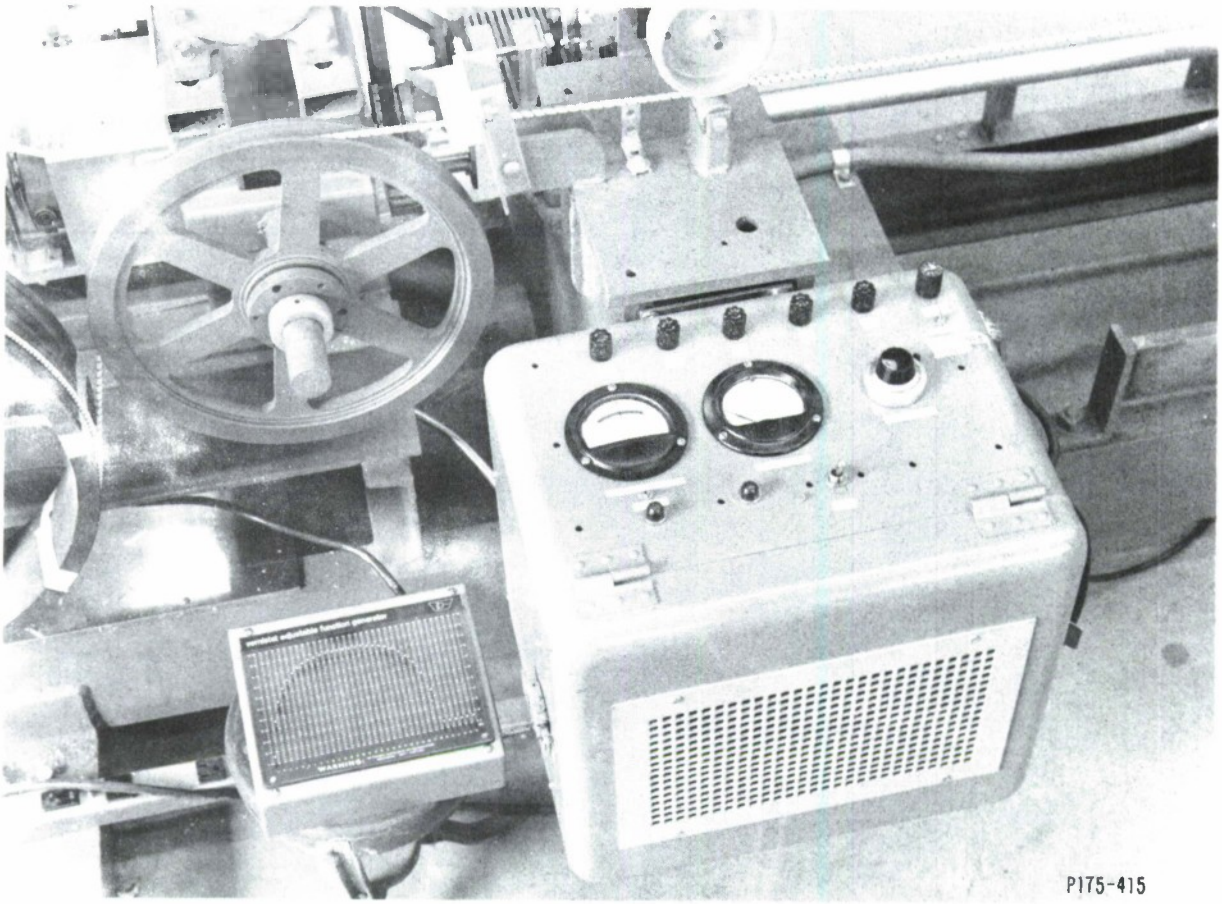

Fig. 5. The control panel (right) and program table (left). The slider positions give a pictorial display of the output voltage function.

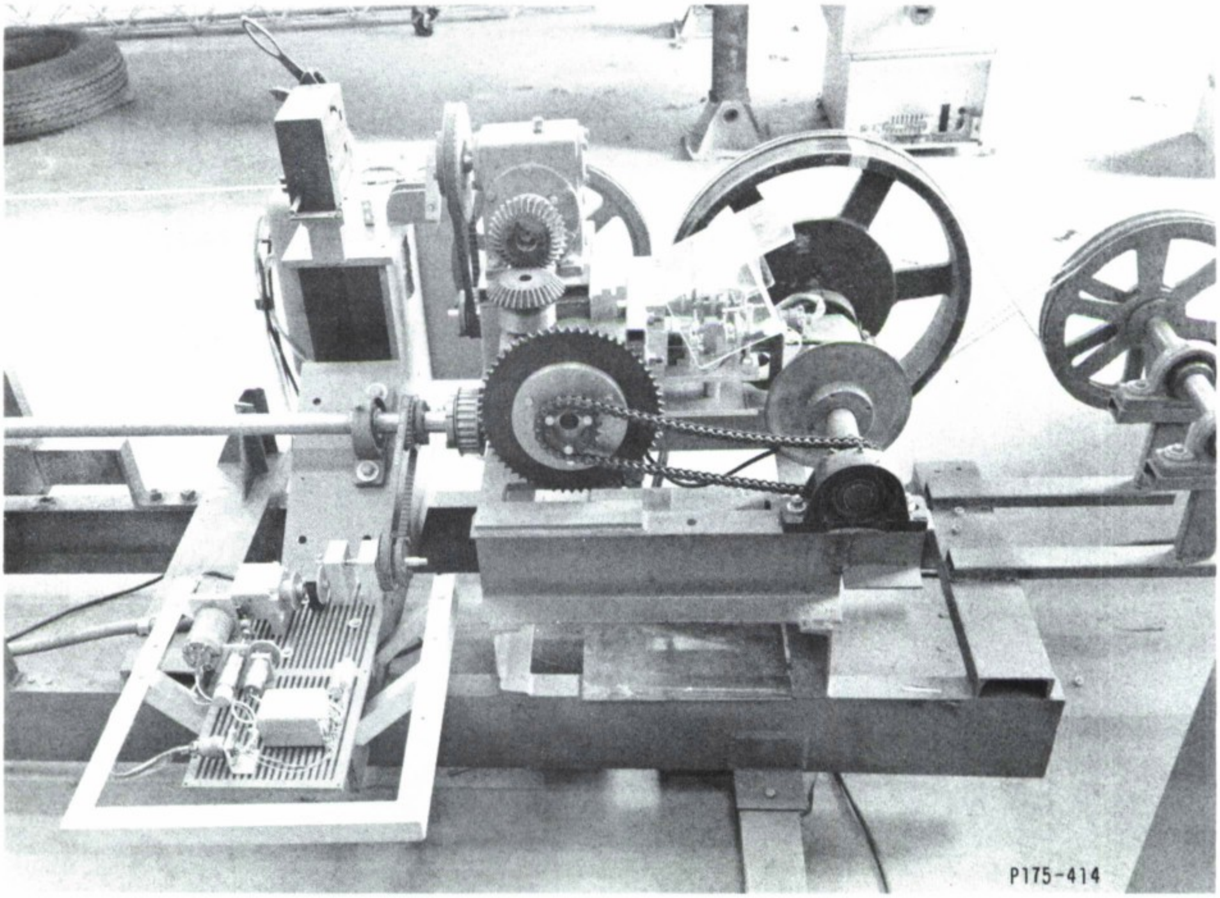

Fig. 6. Rear view of taping machine showing some of the servo components on the mounting plate (near left).

III. Machine Operation

After some preliminary readjustments of gain, gear alignment and feedback filtering, the machine was ready for a trial run. For demonstration purposes, it was judged to be unnecessary to wind a full length (1000 ft.) coil. Accordingly, the gearing between the capstan and the multi-turn potentiometer of the ratio controller was set to sweep the potentiometer through its whole range while only 100 ft. of core passed through the machine. The sliders on the program table were positioned as shown in Fig. 5 to define a turns density variation rising linearly from 3 turns/inch to 19 turns/inch over the first 33.3 ft. staying constant at 19 turns/inch for the next 18.2 ft. and falling linearly back to 3 turns/inch over the final 33.3 ft. giving a total wound length of about 85 ft.

The resulting coil, wound with 18 AWG aluminum magnet wire on a 0.180 in. diameter white foam polyethene single conductor core, is shown in Fig. 7 wound as a single layer on a reel. The variation in turns density from one end to the other is readily apparent.

Figure 8 shows the turns density as a function of position along the core. It was obtained by measuring the taping head speed with a tachometer and chart recorder. Since the capstan speed is constant, the taping head speed is directly proportional to the turns density. (That the turns-density profile is approximately trapezoidal whereas the contour traced by the slider positions in Fig. 5 is approximately parabolic is due to the fact that the gear ratio of the ball and disc drive is not a linear function of the displacement of the linear actuator.)

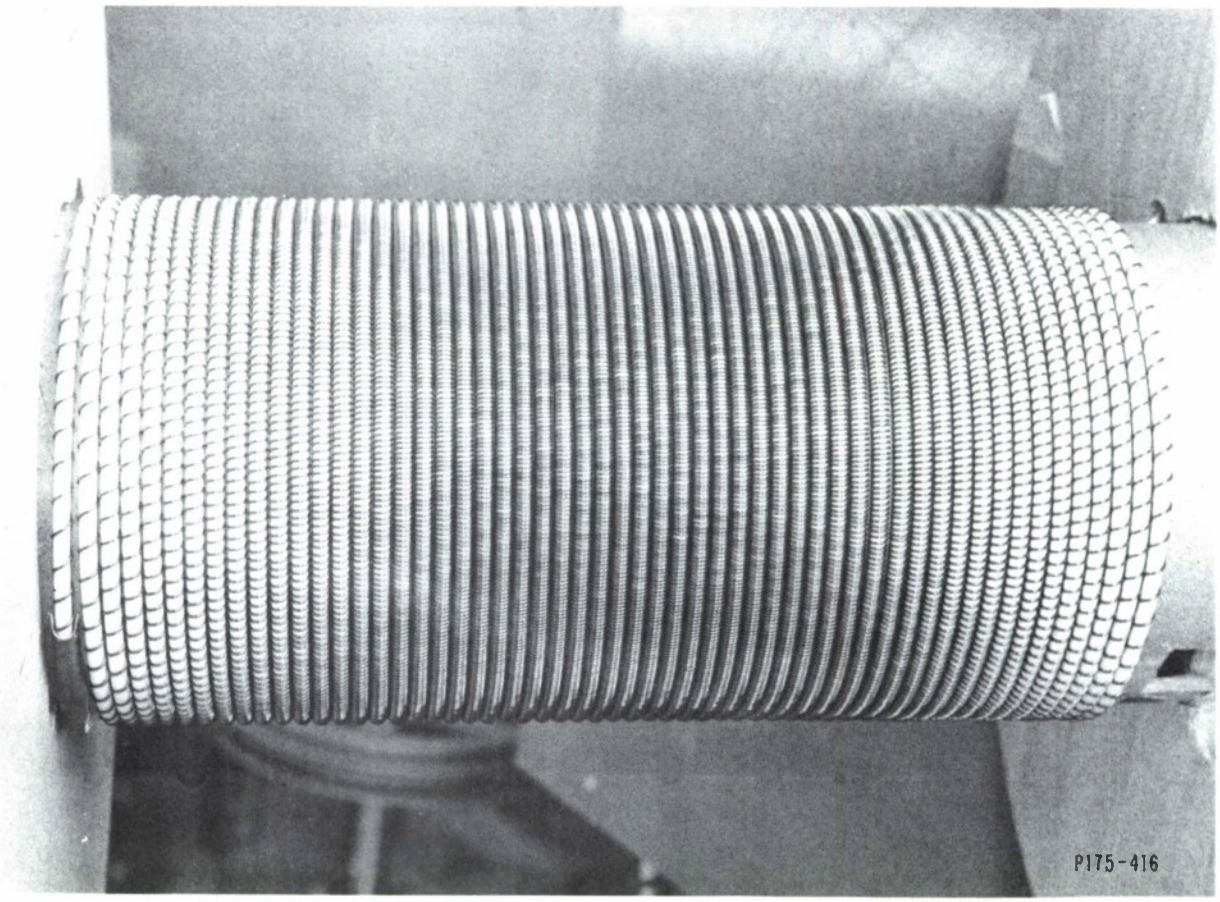

Fig. 7. The test winding on a six-inch diameter cylinder.

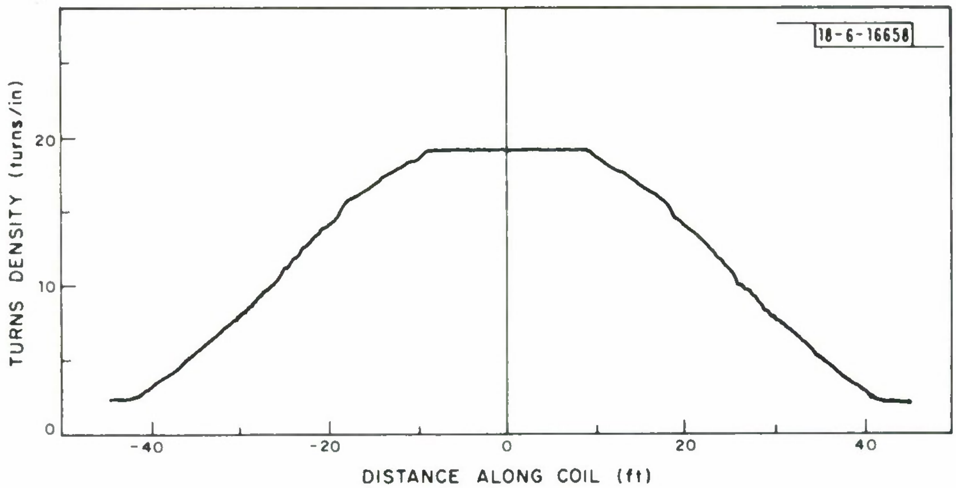

Fig. 8. Turns-density profile of test winding.

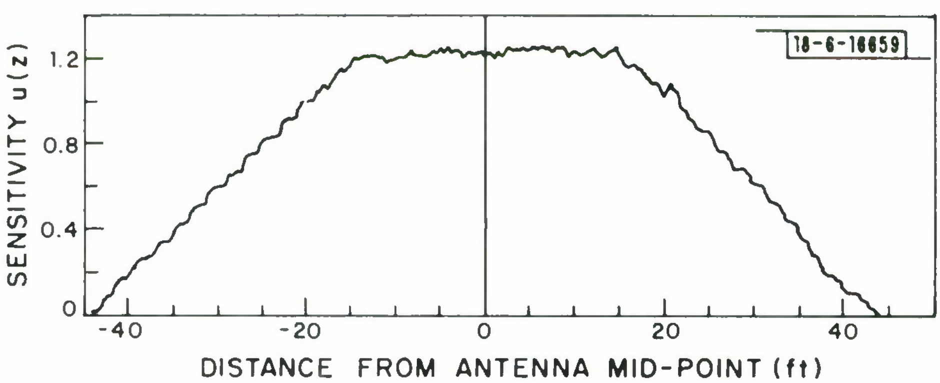

Fig. 9. Sensitivity profile of the 90-ft. version of the latest Lincoln antenna design [6].

Shown for comparison in Fig. 9 is the sensitivity profile of the 90 ft. tapered profile version of the previous Lincoln antenna design [6]. It is readily apparent that the new winding method produces a turns-density profile which eliminates the step discontinuities of the previous method and, in addition, is much smoother than its core permeability profile.

Another comparison of the smoothness is given in Fig. 10, which shows, in expanded scale, a section of turns density profile produced by the modified machine together with a section of the core permeability profile of the latest Lincoln antenna design [6]. The two curves show clearly that the turns density variation produced by the modified machine would add a negligible amount to the total profile roughness. The core permeability variation would remain the dominant source of profile roughness even if it were reduced considerably.

IV. Conclusions

The modifications made to a conventional cable manufacturer's concentric taping machine give it the ability to wind a long coil with an arbitrary pre-programmed turns density variation. The control is precise enough for the modified machine to be of value in attaining the smoothly varying turns density required for the signal winding of a towed ELF loop antenna.

Acknowledgments

Thanks are due to John Lally and David Clark of New England Wire Machinery Company for the quality of the machine they built for us and to Peter Graneau of Underground Power Corporation for his expert guidance through the world of cable making.

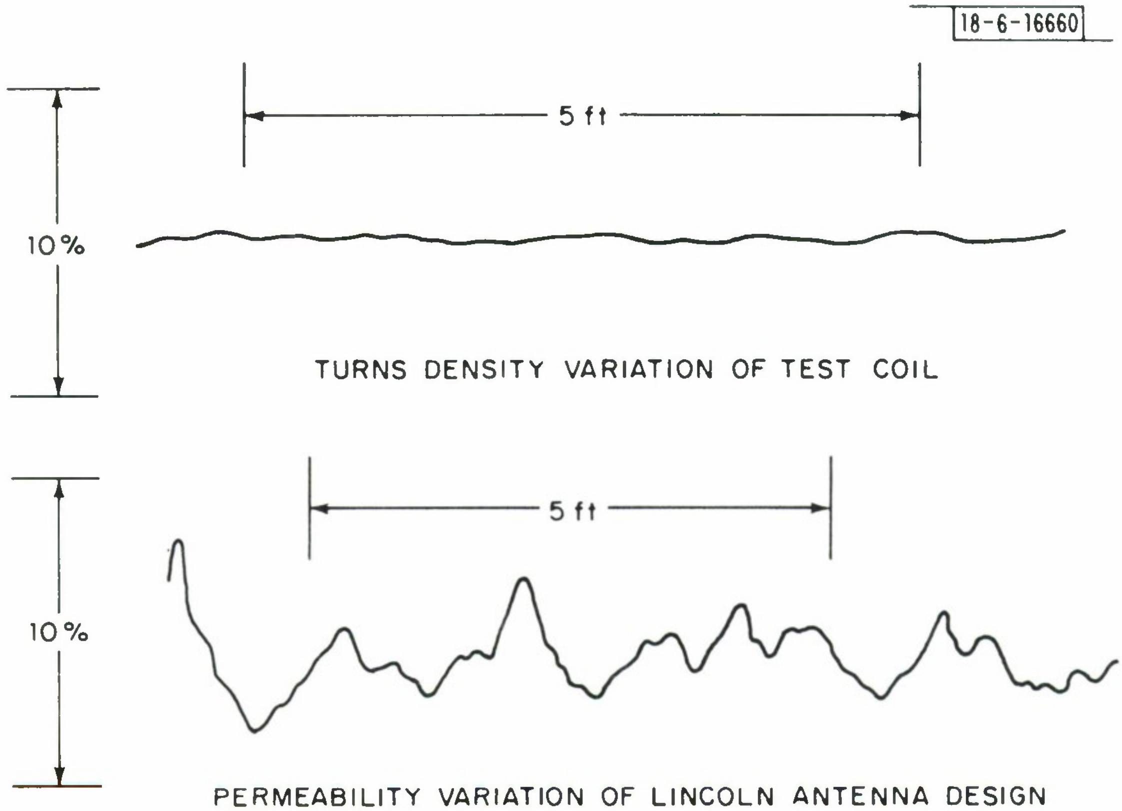

Fig. 10. The variations in profile of the turns density of the test winding and of the core permeability of the latest Lincoln antenna design [6].

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1. REPORT NUMBER ESD-TR-75-176	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Winding a Long Coil with a Pre-Programmed Turns Density Variation		5. TYPE OF REPORT & PERIOD COVERED Technical Note
		6. PERFORMING ORG. REPORT NUMBER Technical Note 1975-30
7. AUTHOR(s) Burrows, Michael L. and Prince, S. Hardy		8. CONTRACT OR GRANT NUMBER(s) F19628-73-C-0002
9. PERFORMING ORGANIZATION NAME AND ADDRESS Lincoln Laboratory, M.I.T. P.O. Box 73 Lexington, MA 02173		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element 11403N Project No. 1511
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Electronic Systems Command Department of the Navy Washington, DC 20360		12. REPORT DATE 27 May 1975
		13. NUMBER OF PAGES 24
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Electronic Systems Division Hanscom AFB Bedford, MA 01731		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

ELF antenna	sensitivity profile tapering	concentric tapering machine
turns density	capacitive tapering	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A conventional cable manufacturer's concentric taping machine has been modified to wind a long solenoidal winding with a smooth pre-programmed turns density variation. An interpolating function generator with many adjustable set points is used to define the function of coil length that the turns density is to follow. A machine having this capability is needed to provide a towed ELF loop antenna with the smoothly tapered sensitivity variation it requires to discriminate against vibration noise.

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